

THE THIRD LONG SHUTDOWN (LS3) OF THE CERN ACCELERATOR COMPLEX

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Abstract

The Large Hadron Collider (LHC) operation began in 2008. Its superconducting equipment requires a cool-down/warm-up cycle lasting several months to access some key elements such as superconducting magnets, making annual shutdowns impractical and obliged for a change in programmed stops paradigm. A new lifecycle management approach for programmed stops was therefore necessary. The large interventions were grouped and performed during long shutdowns (LSs). They include maintenance, consolidation and upgrades. LSs last about three years and are scheduled typically every six years. Since the LHC depends on its chain of preceding injectors, this approach was extended to the entire CERN accelerator complex. This paper briefly outlines the methodology used to plan, prepare and coordinate these LSs and presents the interventions and main upgrades planned for the upcoming LS3, scheduled to start mid-2026 for the LHC. The paper highlights various projects, aimed at improving safety, performance, and operational availability as well as implementing new technologies and providing new facilities for the particle physics community.

CERN ACCELERATOR COMPLEX LIFECYCLE

Most of the Large Hadron Collider (LHC) superconducting magnets operate at temperatures below 2 K to maximise magnetic field strength while maintaining an adequate operational margin. This requires cooling approximately 36 000 t. of magnet cold masses via the LHC cryogenic system. To achieve and sustain this temperature, around 130 t. of helium is cooled by eight cryogenic plants.

The cryogenic system is designed to permit maintenance of the cryogenic plants, particularly major overhauls required after about 40 000 hours (≈ 5 years of operation), while maintaining the LHC at cold standby temperatures¹, around 80 K. However, this capability has not yet been used, as previous long shutdowns (LSs) involved significant interventions on the superconducting magnet circuits [1-3] to be performed at room temperature in all the 8 LHC sectors. This will again be the case during LS3 [4].

The cool-down or warm-up of a single LHC sector typically takes 7 and 4 weeks respectively. For the entire accelerator, each phase usually takes between four and five months, constrained by cryogenics inventory logistics and other activities carried out during these transient

phases [5]. Figure 1 illustrates the average temperature of the 8 sectors at the beginning of LS2, with the warm-up start dates artificially aligned. In practice, the entire process took approximately 4 months. Cool-down phases are often more complex, as thermal cycling may be required to resolve nonconformities identified only at cold or during the cool-down phase.

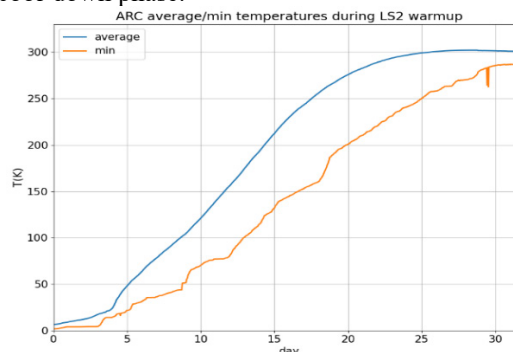


Figure 1: LS2 actual warm-up.

Before the LHC era, annual shutdowns were taking place around the end of year to maintain and upgrade the accelerators, detectors and the infrastructure as these interventions are not compatible with the operation of the accelerators. This approach would have been largely inefficient and impractical considering the large time constant of the LHC. A new lifecycle management approach was therefore devised and applied.

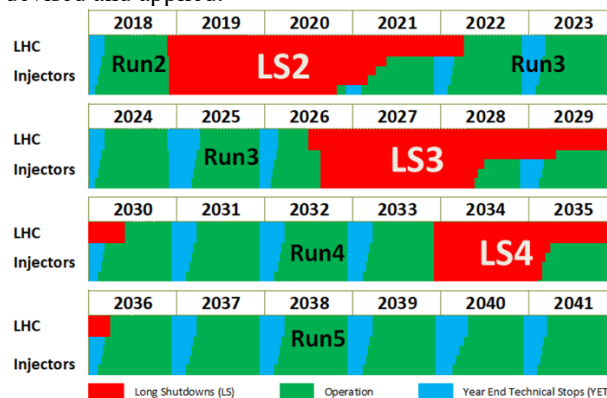


Figure 2: Simplified CERN long-term schedule.

The large interventions requiring the warm-up of the LHC are grouped and performed during programmed LSs, typically every six years. Their duration is optimised to guarantee the longest operation periods possible. This is illustrated in the simplified long-term schedule for the CERN accelerator complex in Fig. 2, showing the alternation between LS and operation periods, the so-called Run.

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¹ The same applies to the LHC experiments superconducting magnets.



Figure 3: LS3 period.

PREVIOUS LONG SHUTDOWNS

The first LS [6], triggered by the need to consolidate the magnet interconnections splices [1, 2], started mid-February 2013 and the beam was back in the LHC early 2015 with the first splash events² on 7 April.

The second LS [7-11] was planned for upgrading the injectors complex to increase the beam intensity and brightness in the LHC injectors [12] to match the challenging requirements of the High-Luminosity LHC (HL-LHC) project. Operation during Run2 revealed the need to consolidate the LHC dipole diode busbar insulation system [3]. The ALICE [13] and LHCb [14] detectors were also largely upgraded. This was complemented by extensive consolidation and maintenance work to ensure high availability of the accelerator complex during Run3.

THE LS3 TIME WINDOW

The High-Luminosity LHC (HL-LHC) project [15, 16], the major planned upgrade of the LHC, aims at increasing the LHC integrated luminosity by an order of magnitude, expanding its discoveries potential, allowing the observation of rare events and the deeper analysis of known mechanisms. To fully exploit the dramatically increased number of collisions, the LHC detectors will also be upgraded during LS3, mainly ATLAS [17] and CMS [18] while large upgrades are planned for ALICE and LHCb during LS4.

The LHC depends on the injectors chain starting from sources and linear accelerators passing through several intermediate accelerator complexes housing also experimental areas with broad and diverse physics programmes [19, 20]. To optimise the overall CERN physics results output by avoiding missing the opportunity to take beams, other projects and consolidation interventions are executed during the same period to upgrade and extend injectors complex accelerator and the related experimental areas.

The LS3 time window is shown in Fig. 3. The LS3 will last from about 1.5 years for the Linac4 (L4) to 47 months for the LHC.

LS3 COORDINATION

Building upon the extensive experience and refined methodologies developed and enhanced during LS1 and LS2 [21-24], a coordination structure for LS3 was established. It adheres to the same principles while incorporating the lessons learned.

² Splash events are used by the experiments to test their numerous sub-detectors and to synchronise them with the LHC timing.

LS3 Core Team (CT)

The LS3 CT, comprising a dozen experts with all the necessary competencies, has been formed. This team includes specialists in facility coordination, planning, operation, logistics, and safety. Significantly, the team now includes operational safety experts, reflecting the lessons learned. Radiation protection is also a key driver in the coordination of LS3, aiming at minimising radiation doses received by the intervening teams. Given its high priority, HL-LHC is directly represented within the LS3 CT. The team is fully equipped to ensure a smooth transition to the operational period at the end of LS3. This is particularly critical as the restart will be gradual, spanning over more than two years (Fig. 3).

Priorities

The priorities, aligned with CERN's overall strategy, have been established for the LS3 interventions (Table 1).

Table 1: LS3 Priorities

Priority	Domain	Comment
P1	Safety	Health, safety and environment
P2	Run3 & 4 objectives	Luminosity targets and availability
P3	HL-LHC	Machine and LHC Experiments
P4	Approved projects	Sub priorities being defined
P5	Approved studies	Sub priorities being defined
P6	Others	

Each activity is classified according to this list and analysed with the help of the PLAN tool [25], a tool developed to centralise, collect and optimise, at a macroscopic scale, all activities to be performed during LS3, including those postponed from LS2. The priority, the allocated time, the availability of human resources and the expected equipment readiness dates are decisive whether to include activities in the LS3 programme. Some activities will have to be postponed to a future programmed technical stop or LS.

Projects

The CERN's accelerator complex [19, 20] is composed of three (sub-)complexes³. It is impossible to mention here

³ The transfer lines connecting accelerators and experimental areas are integrated into the relevant complexes, with clearly defined boundaries. Managing these interfaces is an extra layer of complexity for the coordination efforts.

all the activities and projects that will take place during LS3. The main ones are listed below, by complex.

In the LHC complex:

- The HL-LHC deployment aiming at increasing the LHC integrated design luminosity by an order of magnitude [15, 16].
- The upgrade and maintenance of the LHC experiments, principally ATLAS [17] and CMS [18], to use the enhanced LHC performance resulting from the HL-LHC project deployment.
- The Beam Screen Treatment project to reduce the beam induced heat loads and mitigate degradations, observed after each LS, by depositing a thin amorphous carbon layer on selected beam screens covering about 30 % of the LHC arcs length [4].

In the Super Proton Synchrotron (SPS) complex:

- The consolidation of the North Area to renovate the infrastructure and upgrade beam equipment to ensure high performance and availability during Run4 [26].
- The comprehensive transformation of the Experimental Cavern 3 in the North Area (ECN3) with the complete removal of the existing infrastructure and detectors, followed by a significant upgrade and the installation of the Beam Dump Facility for the future Search for Hidden Particles experiment as part of the High-Intensity ECN3 project [27].
- The Advanced WAKEfield Experiment (AWAKE) programme aims to develop and demonstrate proton-driven plasma wakefield acceleration as a novel technique for accelerating particles to high energies over short distances. It is divided in several phases. During LS3, the dismantling of the CERN Neutrinos to Gran Sasso (CNGS) Target area and the preparation of AWAKE next phases will take place [28].

In the Proton Synchrotron (PS) complex

- The Isotope mass Separator On Line (ISOLDE) facility will undergo major upgrades: enhancement of the proton beam transfer line to raise beam energy to 2.0 GeV, increasing the range and yield of radioactive isotopes and full renovation of two beam dumps to meet modern radiation protection and operational standards, preparing for higher beam power. [29, 30].

Consolidation of the personal safety system, of the technical galleries, of the electrical transmission and distribution networks, de-cabling and cabling, and the construction of a new building for processing and testing superconducting radio frequency cavities [31] are among the numerous CERN wide projects under the umbrella of the LS3 coordination. In addition, large maintenances and consolidations of infrastructure and equipment are carried out.

The LS3 scope will be reviewed and frozen at the “Countdown to LS3” event, planned in September 2025. It will also be the opportunity to identify the remaining issues to be addressed before the start of LS3.

Challenges

For the LHC complex, LS3 is 47 months beam to beam: fitting all activities in this temporal window, both for the

LHC machine and the experiments will be extremely challenging considering safety aspects, coactivity and access restrictions without forgetting resources limitations.

To profit as early as possible from the enhanced accelerators performance resulting from the LS3 interventions, some facilities stop operating earlier to carry out their activities and be ready to take beam as early as available. The first one is the AWAKE facility, stopping operation on 1 June 2025 followed by ISOLDE at the end of 2025. Physics operation will progressively restart in 2028 up to mid-2030. This was already the case during LS1 and LS2 but was spanning over less than one year. For LS3, the overlap between LS3 interventions and operation at the start of Run4 will last more than two years (Fig. 3) with resources stretched between the support to operation and the LS3 activities.

Behind the scenes, logistics and space management are monumental tasks: handling 24 000 m² of storage requests, including radioactive materials, and managing 18 000 m² of buffer zones and worksite infrastructure. These are a must to ensure seamless workflow.

Although not directly under LS3 coordination, equipment readiness for installation is meticulously monitored in close collaboration with the project teams to anticipate delays and develop mitigation strategies. The goal is to prevent a domino effect and to minimise the overall impact on the LS3 timeline. This demands a thorough understanding of dependencies and constraints, as well as effective communication with all stakeholders.

Undertaking this endeavour, the authors, drawing on the experience from past LSs, recognize that the journey will not be smooth. Challenges such as nonconformities, delays in equipment deliveries, adjustment of priorities, and resource limitations will have to be managed. To address these issues, resources will need to be dynamically reallocated, schedules reshuffled, and pragmatic solutions implemented to achieve the (top) objectives of LS3.

CONCLUSION

LS3 is a pivotal phase for CERN. In addition to the deployment of the HL-LHC project and significant upgrades to the ATLAS and CMS experiments, it includes comprehensive consolidation, maintenance, and enhancements across the accelerator complex to ensure long-term performance. As the largest and most diverse programme since the LHC installation, LS3 requires a coordinated effort to ensure its success and maximise benefits across the CERN accelerator complex. Planning is already well underway. LS3 presents a significant opportunity to enhance the accelerator infrastructure, further improving its already high performance, reliability, and availability.

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